NOCTURNAL HABITAT USE BY JUVENILE CHINOOK SALMON IN NEARSHORE AREAS OF SOUTHERN LAKE WASHINGTON, A PRELIMINARY INVESTIGATION, 2000

by

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ABSTRACT

To provide preliminary information on nocturnal habitat use relative to shoreline development, nearshore areas of southern Lake Washington were surveyed for juvenile chinook salmon (*Onchorynchus tshawytscha*) during winter and spring, 2000. Snorkeling was evaluated as a technique for surveying fish in nearshore lake areas. Lake Washington is a highly altered environment with extensive development along the shoreline. Juvenile chinook salmon are found in the lake between January and July, primarily in the littoral zone. Little is known of their habitat use in lakes, as chinook salmon rarely occur in lakes throughout their natural distribution.

Nighttime snorkeling was a useful method to observe chinook salmon in nearshore areas < 1 m deep. Snorkelers could easily locate, approach and identify chinook salmon, and mark their locations accurately for micro-habitat measurements. Nocturnal distributions of juvenile chinook salmon were related to slope, substrate, and depth. We observed the highest densities of juvenile chinook salmon along the shallowest depth contour surveyed (0.4 m compared to 0.7 m), in areas with small to fine substrate (< 50 mm), and in areas having a gradual slope. Few chinook salmon were observed beneath over-water structures, however it was not clear whether low densities were due to an avoidance of these structures or because of other factors (e.g., slope and substrate). Based on their distribution relative to piscivorous fishes, we believe juvenile chinook salmon in Lake Washington are selecting nearshore habitats according to substrate- and depth-dependent risk of predation. Although further study is needed, these data suggest some shoreline development activities (e.g., rip-rapping, creating steep and/or deep shorelines with bulkheading, and building over-water structures) create habitat avoided by juvenile chinook salmon at night. We plan to expand this study in 2001 by increasing the survey effort, surveying other habitats and areas of the lake, beginning an investigation of daytime habitat use, and possibly experimentally testing the use of over-water structures and vegetation.

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INTRODUCTION

Across their natural distribution, chinook salmon (*Onchorynchus tshawytscha*) primarily occur in large rivers and coastal streams (Meehan and Bjornn 1991) which flow directly to salt water. An important run of wild chinook salmon, however, occurs in the Cedar River, which flows into Lake Washington. Cedar River chinook salmon were recently listed as threatened under the Endangered Species Act (March 1999) as part of the Puget Sound Evolutionarily Significant Unit. Juveniles migrate from the Cedar River into Lake Washington beginning as early as January (Seiler 2000), and may be present in the lake for 5-6 months before entering Puget Sound. While in Lake Washington, juvenile chinook salmon are primarily found in the littoral zone (Fresh 2000).

Historically, the Duwamish River watershed, which included the Cedar River, provided both riverine and estuarine habitat for indigenous chinook salmon. Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered (see Weitcamp et al. 2000). Most importantly, the Cedar River was diverted into Lake Washington from the Duwamish River watershed, and the outlet of the lake was rerouted through the Ship Canal, an 8.6 mile artificial waterway lacking a natural estuary. These activities changed fish migration routes and environmental conditions encountered by migrants. Cedar River chinook salmon survived drainage pattern alterations, possibly in part due to supplementation activities.

Today, the largest run of wild chinook salmon in the Lake Washington system occurs in the Cedar River. Cedar River chinook salmon are considered “ocean-type” or fall run. Adults enter into the Lake Washington system from Puget Sound at Chittenden Locks in June. Peak upstream migration past the locks usually occurs in July. Adult chinook salmon begin entering the Cedar River from Lake Washington in September and continue until November. Spawning in the Cedar River occurs from October to December with peak spawning activity usually in November.

Juvenile chinook salmon in the Cedar River begin emerging from the gravel in early January and continue into March. There are two groups of migrants in the Cedar River (Seiler 2000). A large early group migrates to Lake Washington as fry during January-March. A second smaller group rears in the Cedar River for an extended period of time and then migrates to Lake Washington as larger juveniles, mid-May to early-July. Both groups outmigrate from the lake as smolts during June and July.

The shoreline of Lake Washington is extensively developed (Kohler et al. 2000, Weitkamp et al. 2000). Land use along the lake is mostly residential, but also includes some recreational and industrial areas. To reduce erosion and improve access, shorelines are commonly armored with rip-rap or bulkheads resulting in steep slopes (Kahler et al. 2000) and little shallow water area (< 1 meter (m) deep). Over-water structures shading nearshore areas include docks, boat houses, houses, and decks. The few "undeveloped" shoreline areas are relatively small (most <250 m in length) and separated by long distances.

Little is known about chinook salmon habitat use of lakes, or how it may be affected by shoreline development. Information is needed to allow for proper evaluation of shoreline development proposals relative to listed salmonid populations.

In this study, nighttime snorkeling surveys were used to examine juvenile chinook habitat use of the lake. Based on our previous work in the Cedar River, nighttime snorkeling is more effective in locating juvenile chinook salmon than daytime snorkeling (R. Peters, USFWS, pers. comm.). Results from the 2000 Lake Washington study provide preliminary information on habitat use, an evaluation of our sampling techniques, and guidance for 2001 sampling efforts.

STUDY OBJECTIVES

1) Evaluate the effectiveness of nighttime snorkeling to survey juvenile chinook salmon in littoral areas.

2) Determine nocturnal habitat use of juvenile chinook salmon in the nearshore areas of Lake Washington.

3) Determine the relationship between habitat use by juvenile chinook salmon and shoreline development.

METHODS

The basic approach of this study was to observe juvenile chinook salmon from a wide variety of habitat types in nearshore areas of Lake Washington. Surveying was focused in the south end of the lake (Figure 1) where juvenile chinook salmon were expected to be concentrated because of the proximity of the Cedar River. Sites were selected based on substrate type, slope, shoreline armoring, and over-water structures. Habitat conditions were similar along the entire length of any one site.

Snorkeling was used to observe juvenile chinook salmon and other fishes at selected nearshore sites. All surveys were conducted during nighttime hours, beginning at least one hour after sunset. Snorkelers swam parallel to shore with an underwater flashlight, identifying and counting fish observed. At gradual to moderately sloping sites, two snorkelers were used, one swimming along the 0.4 m depth contour and the other along the 0.7 m depth contour. At steeper sites, one snorkeler swam 0.5-2 m from the shoreline, depending on slope and structure of the shoreline. When chinook salmon were encountered, they were tallied on a slate and their depth was categorized as in the bottom, middle, or upper third of the water column.

Micro-habitat use was determined for a sub-sample of the chinook salmon observed during each snorkel survey. Individual chinook salmon locations were sampled systematically and marked with weighted flags. Because no preliminary information was available on expected chinook salmon densities, we adjusted the sampling rate (number of chinook salmon locations marked per site) according to the density of chinook salmon observed during each snorkel survey as follows. First, we visually estimated the density of chinook salmon at the beginning of each survey. We then determined the sampling rate in order to mark approximately 10 chinook salmon locations per site. If the number of chinook salmon was <10, the locations for most individual chinook salmon were marked. This sampling method avoided a disproportionately low sample in areas where chinook salmon densities may be low.

Habitat measurements were made at the site- and at the micro-habitat-level. Habitat was measured after snorkeling each site. Lake levels were unchanged between the time a site was snorkeled and when habitat was measured. It is important to note however, habitat could change at a particular site with changes in lake levels, possibly affecting fish use in nearshore areas. Site-level variables measured included: transect length (measured parallel to shore), substrate composition, mean slope, the number and size of docks or other over-water structures, presence of a bulkhead, water temperature (C), and turbidity (NTU). For substrate, we visually estimated the percentage of five pre-defined size categories within 1-m-diameter circles at approximately 10 locations chosen systematically along the length of a site. Substrate categories were: sand (<5 millimeters (mm)), gravel (5-49 mm), cobble (50-249 mm), boulder (≥250 mm), and other (e.g., organic, wood, metal). The mean slope of each site was estimated by measuring the distance from the shoreline out to a water depth of 1 m at 4-6 locations along a site. Slope was determined as 1 / [distance from shoreline], and then averaged for each site. Micro-habitat variables measured at flagged chinook salmon locations were water depth, dominant and subdominant substrate that the fish was associated with, distance to cover, type of cover, and distance to shore. Cover was broadly defined as any in-water or over-water structure that a fish may use to obscure its visibility, and included large wood, boulders, submerged vegetation, over-water vegetation, and artificial structures.

DATA ANALYSIS

For the purpose of this preliminary study we assumed no differences between counts of fish made by different snorkelers. Most surveys were completed by one of 3 snorkelers, but a total of 6 different snorkelers conducted surveys during this study. Future survey efforts will include calibrating counts made by different snorkelers.

The number of chinook salmon observed per survey was converted to a density estimate:

$$\text{chinook} / \text{m}^2 = \text{chinook count} / \text{area snorkeled}$$

where,

$$\text{area snorkeled} = \text{site length} \times \text{effective width.}$$

For purposes of this study, the effective width was defined as the lateral area viewed by a snorkeler when swimming along a longitudinal transect, within which most fish seen could be easily identified and enumerated. The effective width surveyed by a snorkeler varied depending primarily on slope and depth. Effective width was estimated as 3.75 m for surveys along the 0.4 m depth contour, 2.75 m for surveys along the 0.7 m depth contour, and 2 m for areas with slope > 20% at the shoreline. We estimated effective width by testing the ability of snorkelers to view a standard object at several distances along each depth contour (0.4 and 0.7 m) at sites having < 20% slope, and along the shoreline at sites having > 20% slope. Turbidity influenced the effective width and therefore snorkel surveys were conducted only during low turbidity conditions to avoid related visibility problems. When moderate to high turbidity was encountered, snorkel surveys were not conducted at that site until turbidity sufficiently decreased. Turbid areas could usually be avoided by waiting, surveying areas up-wind, or surveying protected shorelines.

Because chinook densities were not normally distributed ($p<0.01$; Kolmogorov-Smirnov test), variables were tested independently using a combination of nonparametric analyses. The number of surveys in each statistical test varied because the conditions at some sites or during some surveys were not appropriate for all test situations. A Kruskal-Wallis test was used to determine if the overall density of chinook salmon changed by month. The density of chinook salmon observed along the 0.4 m and 0.7 m depth contours were compared using a Wilcoxon Signed Ranks test. Use of areas with <20% and >20% mean slope were tested by a Mann-Whitney U test. Categorizing areas as having a slope of < or > 20% was made after determining the number of chinook salmon was considerably higher at sites having <20% slope. A Kruskal-Wallis test was used to determine if fish densities differed along shorelines with and without armoring (bulkheading and rip-rap). Finally, Chi-square tests for goodness of fit (Sokal and Rohlf 1969) were calculated to determine if substrate was selected in a non-random pattern. To evaluate preference or avoidance of each substrate type, electivity indices were calculated (Vanderploeg and Scavia 1979). Preference for a particular substrate type was defined as being used in greater proportion than its availability in the environment. Electivity indices were calculated as follows:

$$E_i = [W_i - (1/n)] / [W_i + (1/n)]$$

where,

$$W_i = [r_i/p_i] / [\sum r_i/p_i]$$

and,

r_i = relative utilization of substrate type i

p_i = relative availability of substrate type i.

Information on substrate use was obtained from individual chinook salmon locations that were marked with weighted flags. Because juvenile chinook salmon were often sub-sampled, the number of chinook salmon using a particular substrate type was weighted based on the total number of chinook salmon counted during a survey. Relative substrate use per survey was thus calculated as follows:

$$r_i = [\text{total number chinook counted / total number chinook flagged}] \times [\text{number flagged chinook locations with dominant substate type i}]$$

Substrate availability was defined as the relative abundance of each substrate type. Substrate availability was calculated based on averaging across substrate samples taken along each transect. The proportion of each substrate type per site was then calculated from the average proportions. Relative substrate availability was then determined as follows:

$$p_i = [\text{proportion of substrate i}] \times [\text{site length}]$$

All statistical tests were computed using SYSTAT 9 (SPSS Inc. 1998).

RESULTS

Snorkeling proved to be a useful method to observe juvenile chinook salmon in nearshore areas of Lake Washington during the night. We observed over 500 chinook salmon during only 9 nights of sampling and were able to easily locate, approach and identify chinook salmon, and mark their locations accurately for micro-habitat measurements.

The effective area surveyed by snorkelers was influenced by physical conditions at the site. The width of transects surveyed was estimated to be 1.5-3.5 m, and varied depending on slope, depth, substrate, and to a lesser extent, by water turbidity. Because slope appeared to be the most important determinant of the transect width surveyed by a snorkeler, fish densities were estimated accordingly.

Results of this study apply only to depths of < 1 m because this is the limit snorkelers could effectively survey for fish. At greater depths, we could not always see chinook because of their small size. We also counted other fish species in nearshore areas (Appendix A). Abundance for some of these fishes, and chinook salmon, may have been underestimated because they were 1) not active and remained in cover, 2) in slightly deeper waters than were effectively surveyed, or 3) were active and avoided snorkelers.

Between March 1 and June 15, 2000, we completed 41 nighttime snorkel surveys at 35 different sites on 9 different dates. For sites with a gradual slope (<20%), 25 surveys were completed with 2 transects per site. On April 4, one survey was completed with only a single transect along the 0.4 m depth contour (Table 1). While at steeper sites (>20% slope), 15 surveys were completed. Over all sites, the mean transect length was 67 m (SD 25.3 m, range 28 to 145 m; Table 2).

A total of 552 chinook salmon were counted during all surveys. At gradual sloping sites, 363 chinook salmon were counted along the 0.4 m depth contour and 111 along the 0.7 m depth contour (Table 3). At steeper sloping sites, 78 chinook salmon were counted.

Juvenile chinook salmon densities were compared on steep (>20%) versus gradual (<20%) sloping nearshore areas. Bulkheaded sites were included in the >20% mean slope category. The density of juvenile chinook salmon was significantly greater at gradual sloping areas compared to steeper sites during all survey months (Mann-Whitney test statistic = 290.0, p = 0.01, Figure 2). However, because slope and substrate are related, further information is needed to determine the relative importance of the two variables on chinook salmon habitat use.

The density of chinook salmon was significantly different by depth, considering surveys at sites with gradual slopes (Wilcoxon Signed Ranks; $P = 0.002$). During March, April, and May, the number of juvenile chinook salmon was higher along the 0.4 m depth contour compared to the 0.7 m depth contour (Figure 3). In June, most chinook salmon counted were distributed along the 0.7 m depth contour.

Juvenile chinook salmon preferred small substrate, and used slightly larger substrate over time, based on separate Chi-square tests of early and late period surveys (March/April: χ^2 = 766.7, d.f. 3; May/June χ^2 = 145.5, d.f. 3; Table 4). Chinook salmon preferred sand (<1-5 mm) during March and April, preferred both sand and gravel (5-50 mm) during May and June, and avoided larger substrate during both periods (> 50 mm; Figure 4). Additionally, based on data collected during repeat surveys completed at three different locations, the size of substrate utilized by juvenile chinook salmon appeared to increase over time,. Each of these survey sites had either primarily sand, gravel, or cobble/gravel substrate. The density of chinook salmon was highest at the sand site during March (Figure 5). Use of the gravel site increased between the March and May surveys, and was highest over the cobble/gravel site in May. In June, no chinook salmon were observed over sand, no data were collected at the gravel site, and a few chinook were observed over cobble/gravel.

Few chinook salmon were observed beneath over-water structures. About 10% of the 10,704 m of nearshore area surveyed was covered by over-water structures, but only 4% (8 of 205 flagged for micro-habitat measurements) of the chinook salmon were observed beneath over-water structures. Over-water structures along surveyed sites included boat docks, boat houses, piers, and houses. Conditions beneath over-water structures varied with respect to slope, substrate, and depth. The substrate beneath over-water structures included a disproportionate amount of rip-rap, bulkheads, and other large substrate in comparison to areas without over-water structures.

Chinook salmon densities were significantly higher along shorelines without armoring (Kruskal-Wallis test statistic 13.91, $p<0.001$; Figure 6). At sites that were armored, more chinook salmon were observed along rip-rapped shorelines than along bulkheaded shorelines in all months surveyed.

Micro-habitat measurements were taken at 205 chinook salmon locations marked with weighted flags. Distance from shore and cover was dependent on where snorkelers swam. We typically covered from the shoreline out to a distance of 6.5 m at gradually sloped sites, and 2 m at steep sites. Overall, chinook salmon were further from shore and cover (straight line distances taken at water level), and in shallower water at gradual sloping sites (< 20% mean slope) compared to steeper sites (Table 5). At gradual sloping sites, chinook salmon were located a mean of 3.7 m from shore (SE 0.2), 8.3 m from cover (SE 0.4), and at a mean water depth of 0.5 m (SE < 0.1). While at steeper sites, chinook salmon were located a mean of 1.6 m from shore (SE 0.2), 1.7 m from cover (SE 0.2), and at a mean water depth of 0.7 m (SE 0.1). Water depth at steeply sloped sites was typically > 0.7 m, and was > 1m at about half of the survey sites. Chinook salmon were mostly seen near the water surface (<0.5 m depth) and very close to shore, regardless of total water depth at these steeply sloped sites. At gradual sloping sites, the majority of chinook salmon were close to the bottom. No temporal pattern was evident in the different micro-habitat measurements.

The mean density of chinook salmon changed through time. Densities in June (0.02 fish/m^2, standard error (SE) 0.02) were significantly less than that observed in earlier months (Kruskal-Wallis test statistic 7.945, $p < 0.05$; Figure 7). Mean density was highest in March but not significantly different from April and May (March: 0.16, SE 0.06; April: 0.08, SE 0.02; May 0.10, SE 0.02). Because survey sites were different across months, differences in the above densities could also be attributed to site habitat. However, densities of chinook salmon also varied through time at three sites in which repeat surveys were conducted. Densities were considerably reduced in June compared to surveys in March and May (Figure 5).

DISCUSSION

Chinook Habitat Use

Juvenile chinook salmon in Lake Washington are known to be abundant in littoral areas (Fresh 2000). Along the shoreline within the littoral zone, we observed that juvenile chinook salmon at night remained close to shore at very shallow depths. They generally were motionless or "resting" at night, and no feeding or schooling behavior was observed. Similar observations of chinook salmon have been made in slow water areas of reservoirs and rivers. In Lower Granite Reservoir on the Snake River, WA, fall chinook salmon were found in shallow nearshore areas (Curet 1993). In free flowing river habitat, fall chinook salmon were most abundant in shallow nearshore areas with reduced current velocity (Dauble et al. 1989) or along the fringes of pools (Hillman et al. 1987). Similarly, juvenile rainbow trout in two Utah reservoirs at night were found in exposed areas such as sand, gravel and cobble, and remained motionless when approached (Tabor and Wurtsbaugh 1991).

Water depths used by juvenile chinook salmon increased over time. This is likely due to fish growth. A positive relationship between fish size and water depth has been observed in salmonids and other fishes. For example, depths used by sub-yearling chinook salmon were related to fish size in the Columbia River (Dauble et al. 1989), and for chinook salmon and other salmonids in smaller streams (e.g., Everest and Chapman 1972; Hillman et al. 1989; Hillman et al. 1987). We did not measure fish length during this study, but a noticeable increase in size of chinook salmon was observed by snorkelers during the study. To further our understanding of juvenile chinook use of depth in nearshore areas, we plan to continue surveys at various water depths in 2001, including areas > 1m deep using scuba divers.

The dominant substrate type utilized by juvenile chinook salmon increased in size through time, suggesting substrate use in the lake may also relate to fish size. Chinook salmon preferred only sand during March and April, but preferred both sand and gravel in May and June, when larger chinook salmon are likely present. A similar pattern was observed in the Cedar River where chinook salmon were associated with substrate that was predominately sand in March, and cobble in June (R. Tabor, unpublished data 1999). This relationship between substrate size and fish size has been demonstrated for salmonids in other stream systems (see Bjornn and Reiser 1991).

Juvenile chinook salmon appear to preferentially select shallow nearshore areas with small substrate, as they were found to use these habitat conditions in disproportion to their availability. Shallow nearshore areas with small substrate are rare in Lake Washington in comparison to armored shorelines (rip rap or bulkheads), which make up over 70% of the shoreline (Toft 2001). Habitat selection in juvenile fish has often been viewed as a trade-off between maximizing growth opportunity and minimizing risk of predation (see Diana 1995, Werner and Hall 1988, Werner et al. 1983). The influence of prey availability on habitat selection of juvenile chinook salmon in Lake Washington is unclear. However, preliminary data suggests that a primary prey item of juvenile chinook salmon (larval Chironomidae) is abundant in many areas of the lake (Koehler 2000). If opportunity for growth is sufficient in many areas of the lake in terms of food availability, why do chinook salmon appear to be selecting habitat that is relatively rare? We believe that the two primary factors influencing habitat selection by juvenile chinook salmon in Lake Washington are substrate- and depth-dependent risk of predation. Considering the distribution of juvenile chinook salmon relative to predators provides evidence for this theory.

Chinook salmon may select small substrate in nearshore areas because predators are less abundant in these areas. Important predators of salmonids in Lake Washington include prickly sculpin (Tabor et al. 1998), smallmouth bass (Fayram 1996, Tabor and Chan 1996), northern pikeminnow (Brocksmith 1999), and cutthroat trout (Nowak 2000). Within nearshore areas <1m deep, these predators appear to be most abundant in areas providing greater structural complexity in comparison to areas chinook salmon were observed during this study (Coble 1975; Pflug and Pauley 1984; Kraai et al. 1991). For example, prickly sculpin (>75 mm TL) in southern Lake Washington were most abundant over cobble/gravel, and decreased in abundance over smaller substrates (Tabor et al. 1998). Whereas chinook salmon surveyed during this study in the same locations exhibited the opposite use pattern (Figure 8). Habitat use by chinook salmon and piscivorous fish in the Lower Snake River showed a similar distributional pattern. The Lower Snake River is primarily slow water habitat with large deep pools in the upper free flowing section, and comprised of relatively deep and slow moving reservoirs in the lower section. Juvenile chinook salmon in the Lower Snake River commonly inhabit shallow sandy areas close to shore (Bennett et al. 1988; Curet 1993; Garland and Tiffan 1999) while the most important predators (smallmouth bass and northern pikeminnow) inhabit nearshore areas with larger substrate or are found in deeper areas, further from shore (Naughton 1998; Piaskowski 1998).

Shallow water could function as a refuge for chinook salmon from piscivorous fishes. Small fish like juvenile chinook salmon may incur a lower mortality rate in these areas. In a field study, survival of small fish and crustaceans decreased with depth, when sampled at 0.15, 0.3, and 0.6 m in non-vegetated nearshore areas of Chesapeake Bay (Ruiz et al. 1993). In two different laboratory experiments, bluegill altered their habitat use in the presence of piscivorous fish by reducing their use of deep water (DeVries 1990) and/or open water (Moody et al. 1983). Spatial distribution patterns of fish and their predators in streams has also been attributed to risk of predation (e.g., Harvey et al. 1988; Hillman et al. 1989).

Risk of predation for chinook salmon changes with size. For many fish, risk of predation from larger piscivorous fish decreases with size, effectively expanding the range of water depth available to larger fishes. This would help explain the increased use of deeper waters by juvenile chinook salmon late in the study season. For example, Werner et al. (1983) observed decreased mortality with size in a field experiment of juvenile bluegill in the presence of piscivorous bass. Conversely, larger fish could be essentially forced into deeper waters due to the increased risk of predation from avian predators (see Power 1987).

Relationship to Artificial Structures

At night, juvenile chinook salmon appear to avoid armored shorelines. These structures are usually associated with slopes >20 % and provide little or no shallow water habitat, conditions that appear to be avoided by juvenile chinook. Rip-rapped areas often have high numbers of predators, and may partly explain limited use by juvenile chinook salmon at night. Two important predators of chinook salmon in Lake Washington, smallmouth bass and prickly sculpin, often use rip-rapped areas (Sammons and Bettoli 1999; Tabor and Chan 1998).

Juvenile chinook salmon were rarely associated with over-water structures at night. These areas typically had steep slopes and large substrate at the shoreline, conditions that appeared unfavorable to juvenile chinook salmon. Further study is needed to determine the affect of these variables on juvenile chinook habitat use. Other factors may also influence use of these areas. Important predators of juvenile chinook salmon are commonly found in these conditions, especially smallmouth bass (Sammons and Bettoli 1999; Tabor and Chan 1998; Pflug 1981; also see Kahler et al. 2000). Food availability may also differ in these areas, although information is needed to determine its affect on juvenile chinook distribution and habitat use.

Juvenile chinook salmon use of artificial structures during the day is not understood, and could possibly increase compared to nighttime. Many fish are known to utilize shaded areas produced by floating or over-water structures, possibly due to the relative visual advantage. Helfman's (1981) theory is that "a fish hovering in shade is better able to see approaching objects and is simultaneously more difficult to see" during the day. Use of more complex habitat by juvenile chinook salmon may also increase. Juvenile rainbow trout in two Utah reservoirs were most often found in rip-rap compared to smaller substrates during the day, and when located away from cover, they were usually in schools and strongly oriented to one another (Tabor and Wurtsbaugh 1991). In 2001, we will use snorkeling to gather preliminary information and evaluate its effectiveness to survey for juvenile chinook salmon in nearshore areas during the day, including beneath over-water structures. We also plan to experimentally test the effect of over-water structures on the distribution of juvenile chinook salmon.

Methodology

Nighttime snorkeling was a useful method to survey juvenile chinook salmon in nearshore areas (< 1 m depth) of Lake Washington. Snorkeling also allowed us to define micro-habitat used by juvenile chinook salmon, which would not be possible using most other methods. Compared to other methods available, snorkeling was easier, safer, less costly, and caused minimal disturbance to fish. To further determine the effectiveness of snorkeling to survey juvenile chinook salmon in nearshore lake environments, we plan to compare snorkeling to beach seining and possibly other forms of netting in 2001.

Although snorkeling appeared effective, we propose to make some changes in 2001. First, the effective width surveyed by snorkelers (lateral area view by snorkelers swimming a longitudinal transect) varied between sites depending on slope, and we corrected data by site prior to analysis according to the estimated difference. However, other factors could influence the accuracy of fish counts, including differences between snorkelers, substrate, and fish size and coloration. In 2001, we plan to further evaluate the effect of physical attributes at a site on the effectiveness of snorkelers, and attempt to adjust for differences between snorkelers to improve the accuracy of fish counts. Second, the effective maximum depth surveyed by snorkeling was about 1 m. In 2001, we plan to use scuba gear to survey deeper waters.

Sampling of micro-habitat use by individual fish may have been inaccurate due to our systematic sampling scheme. Our goal was to sample approximately 10 fish locations per survey, and adjust the sampling rate according to the visually estimated density of chinook salmon along the survey site. However, visually estimating density in the field was difficult because densities were low along many sites, varied greatly between sites, and varied through time. To overcome this problem in 2001, we will either sample micro-habitat for all chinook salmon encountered, or sample systematically by marking the location of every n^{th} fish, where ‘n’ is constant across all surveys.

Summary

The nocturnal distribution and density of juvenile chinook salmon in nearshore areas of southern Lake Washington were related to substrate, slope, and depth during winter and spring, 2000. Habitat use patterns changed over the March to June study period, likely due to increasing fish size. Results from this preliminary study suggest some shoreline development activities (i.e., rip-rap, bulkheading, over-water structures) have created habitat avoided by juvenile chinook salmon at night. Based on their distribution relative to piscivorous fishes, we believe juvenile chinook salmon in Lake Washington were selecting nearshore habitats according to substrate- and depth-dependent risk of predation.

FUTURE STUDY PLANS

This preliminary study suggests that chinook salmon during the night select shallow habitats with small substrates and avoid certain types of shoreline development in Lake Washington, such as bulkheads, rip-rap, and over-water structures. To further understand habitat use patterns of juvenile chinook salmon in nearshore areas of Lake Washington, and the influence of shoreline development, we plan to expand this study in the following ways:

1. Increase survey effort in southern Lake Washington, where chinook salmon are most likely to be concentrated, especially the use of over-water structures and shoreline armoring;

2. Survey other habitats and areas of the lake, including tributary mouths, vegetated areas, large wood, mid- Lake Washington, and Ship Canal;

3. Begin an investigation of daytime habitat use patterns by conducting some nearshore day snorkeling; and,

4. Experimentally test the use of over-water structures and vegetation by juvenile chinook salmon.

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Table 1. Number of snorkel transects surveyed for juvenile chinook salmon by month in 2000, for areas of southern Lake Washington with < or > 20% mean slope. For areas surveyed with < 20% mean slope, two transects were completed with one along the 0.4 m depth contour and one along the 0.7 m depth contour.

	Slope < 20%		
Month	0.4 m	0.7 m	Slope > 20%
March	8	8	3
April	6	5	3
May	7	7	5
June	5	5	4
Total	26	25	15

Table 2. Conditions along sites snorkeled for juvenile chinook salmon in southern Lake Washington, March-May, 2000. Mean slope of each site was categorized as < 20% (1) or > 20% (2). For sites with < 20% mean slope, snorkelers swam along the 0.4 m and 0.7 m depth contours. For sites with > 20% mean slope, snorkelers swam at 0.5 m from the shoreline, regardless of water depth. Dominant substrate refers to the substrate type occurring in the highest proportion along a surveyed site. Percent over-water structure is the proportion of the surveyed site length covered by over-water structures. na = not applicable.

Site	Site length (m)	Slope category	Depth contour (m)	Dominant substrate	% over-water structure
1	75	1	0.4	gravel	0
			0.7	gravel	0
2	111	2	na	boulder	0
3	66	1	0.4	gravel	0
			0.7	cobble	0
4	60	1	0.4	sand	0
			0.7	sand	0
5	63	1	0.4	gravel	5
			0.7	cobble	5
6	70	1	0.4	gravel	0
			0.7	gravel	0
7	50	2	na	boulder	0
8	53	1	0.4	cobble	0
			0.7	sand	0
9	41	1	0.4	sand	0
			0.7	cobble	0
10	40	1	0.4	boulder	0
			0.7	sand	0
11	66	2	na	sand	0
12	42	1	0.4	cobble	0
			0.7	cobble	0
13	37	2	na	boulder	66
14	94	1	0.4	gravel	35
			0.7	cobble	35
15	33	1	0.4	sand	0
16	130	1	0.4	boulder	6
			0.7	gravel	6
17	145	2	na	cobble	13
18	68	2	na	cobble	0
19	57	1	0.4	sand	0
			0.7	gravel	0
20	60	1	0.4	sand	5
			0.7	sand	5

Table 2. Continued.

Site	Site length (m)	Slope category	Depth contour (m)	Dominant substrate	% over-water structure
21	106	2	na	cement	0
22	62	2	na	boulder	24
23	40	1	0.4	sand	10
			0.7	cobble	10
24	72	2	na	sand	8
25	73	2	na	boulder	79
26	61	1	0.4	gravel	0
			0.7	gravel	0
27	28	1	0.4	gravel	18
			0.7	gravel	18
28	40.5	1	0.4	sand	12
			0.7	sand	12
29	65	2	na	cobble	12
30	69.5	2	na	boulder	81
31	80.5	2	na	boulder	86
32	130	2	na	cement	8
33	36	2	na	sand	0
34	52	1	0.4	sand	0
			0.7	sand	0
35	80	1	0.4	cobble	0
			0.7	gravel	0

Table 3. Number and density (chinook/m^{2}) of juvenile chinook salmon at snorkeled sites in nearshore areas of southern Lake Washington having < or > 20% mean slope, March-June, 2000. na = not applicable, sd = standard deviation.

				Number of chinook		Chinook/m^2	
	Survey #	Date	Site	0.4 m	0.7 m	0.4 m	0.7 m
			Slope < 20%				
	1	1-Mar	1	1	0	0.00	0.00
	3	1-Mar	3	4	0	0.02	0.00
	4	1-Mar	4	19	5	0.11	0.04
	5	6-Mar	5	22	1	0.12	0.01
	6	6-Mar	6	8	4	0.04	0.03
	8	22-Mar	8	44	12	0.28	0.11
	9	22-Mar	9	61	8	0.50	0.10
	10	22-Mar	10	3	1	0.03	0.01
	12	4-Apr	12	7	3	0.06	0.04
	14	4-Apr	14	25	21	0.09	0.11
	15	4-Apr	15	3	na	0.03	na
	16	20-Apr	16	12	6	0.03	0.02
	19	20-Apr	19	26	4	0.15	0.04
	20	20-Apr	20	12	3	0.07	0.03
	23	2-May	4	18	4	0.10	0.03
	24	2-May	1	41	5	0.18	0.03
	25	2-May	3	10	2	0.05	0.02
	26	2-May	23	7	6	0.06	0.08
	29	16-May	26	11	0	0.06	0.00
	30	16-May	27	8	3	0.10	0.05
	31	16-May	28	16	3	0.13	0.04
	33	1-Jun	35	2	1	0.01	0.01
	35	1-Jun	6	2	19	0.01	0.14
	39	15-Jun	4	0	0	0.00	0.00
	40	15-Jun	1	1	0	0.00	0.00
	41	15-Jun	34	0	0	0.00	0.00
sum				363	111	2.21	0.92
count	26	9	20				
mean						0.17	0.09
sd						0.42	0.21

Table 3. Continued.

	Survey	Date	Site	Number of chinook	Chinook/m^2
			Slope > 20%		
	2	1-Mar	2	6	0.05
	7	22-Mar	7	1	0.01
	11	22-Mar	11	20	0.30
	13	4-Apr	13	0	0.00
	17	20-Apr	17	2	0.01
	18	20-Apr	18	5	0.04
	21	2-May	21	14	0.07
	22	2-May	22	8	0.06
	27	2-May	24	19	0.13
	28	16-May	25	0	0.00
	32	16-May	29	1	0.01
	34	1-Jun	30	0	0.00
	36	1-Jun	31	1	0.01
	37	1-Jun	32	1	0.01
	38	15-Jun	33	0	0.00
sum				78	0.69
count	15	8	15		
mean					0.09
sd					0.19

Table 4. Substrate use by juvenile chinook salmon during late winter and spring in southern Lake Washington, 2000, and Chi Square analysis. Percentage of chinook salmon using each substate type at each site was weighted based on the following calculation: number of flagged locations × (total chinook count / number of flagged locations).

Substrate category	Observed (weighted)	Expected	χ^2	Percent observed (weighted)
		March/April		
Sand	238.0	54.4	619.1	74.6
Gravel	70.1	111.1	15.1	22.0
Cobble	5.5	80.2	69.5	1.7
Boulder	5.3	73.3	63.0	1.7
Total	319	319	766.7	100
		May/June		
Sand	50.5	28.9	16.1	36.1
Gravel	118.5	60.0	57.0	58.0
Cobble	10.1	42.5	24.7	3.1
Boulder	0.0	47.7	47.7	2.7
Total	179.1	179.1	145.5	100

Table 5. Summary statistics for variables measured at juvenile chinook salmon locations marked (n) in nearshore areas with < or > 20% slope in southern Lake Washington, March-June, 2000. Standard error (SE) was computed from the pooled variance. CI = confidence interval; na = not applicable.

		Distance from bank (m)			Distance from cover (m)			Depth of water (cm)		
		Slope < 20%								
	n	mean	SE	95% CI	mean	SE	95% CI	mean	SE	95% CI
March	67	4.1	0.2	0.1	10.9	0.7	1.0	0.43	< 0.1	< 0.1
April	48	2.1	0.2	0.1	1.9	0.2	0.1	0.48	< 0.1	< 0.1
May	46	4.7	0.6	0.7	11.5	1.1	2.4	0.47	< 0.1	< 0.1
June	6	2.9	0.5	0.8	2.8	0.4	0.5	0.47	0.1	< 0.1
Total	167	3.7	0.2	0.1	8.3	0.4	0.4	0.45	< 0.1	< 0.1
		Slope > 20%								
March	1	2.5	na	na	4.30	na	na	0.5	na	na
April	6	1.4	0.3	0.3	1.4	0.7	1.5	0.5	< 0.1	< 0.1
May	16	1.6	0.3	0.2	1.6	0.3	0.2	0.8	0.1	< 0.1
June	5	1.7	0.2	0.2	1.5	0.2	0.2	0.7	< 0.1	< 0.1
Total	28	1.6	0.2	0.1	1.7	0.2	0.1	0.7	0.1	< 0.1

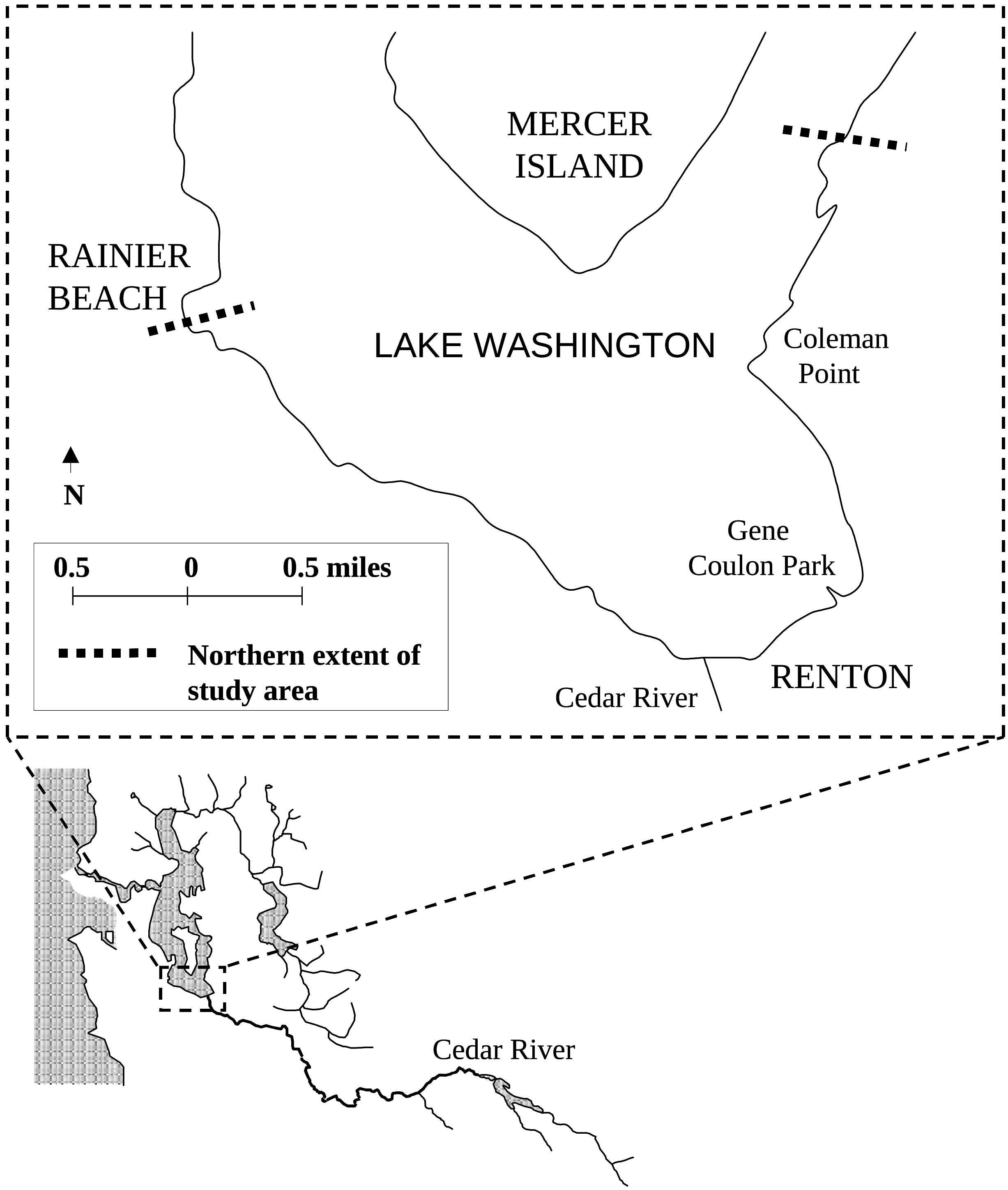


Figure 1. Map of study area in southern Lake Washington, March-June, 2000. No surveys along Mercer Island were conducted.

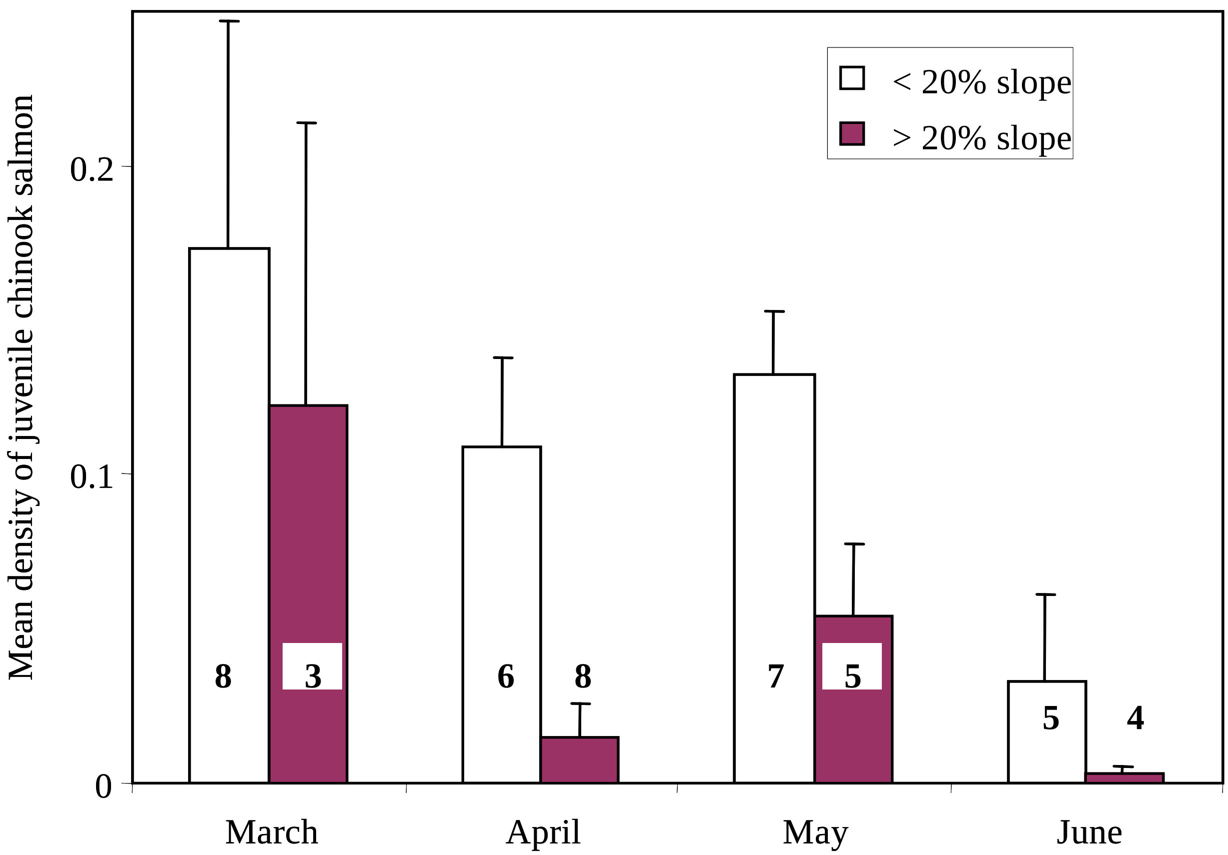


Figure 2. Mean density (fish/m^2) of juvenile chinook salmon (+ 1 SE) at nearshore survey sites in southern Lake Washington having less than or greater than 20% slope, March-June, 2000. Numbers within or above each bar indicate the number of surveys conducted during each period.

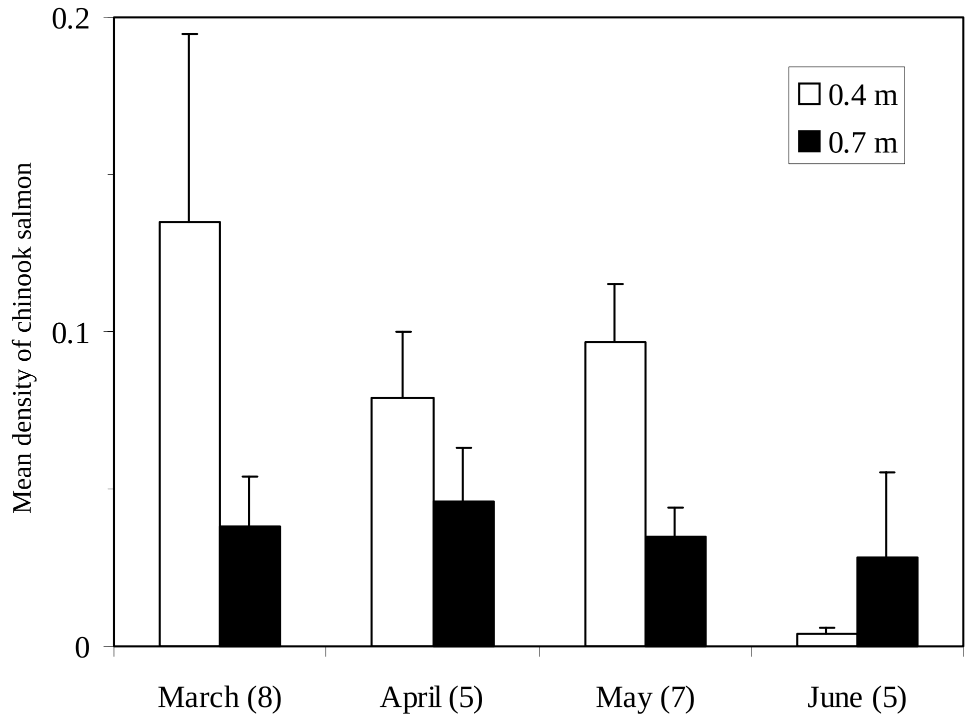
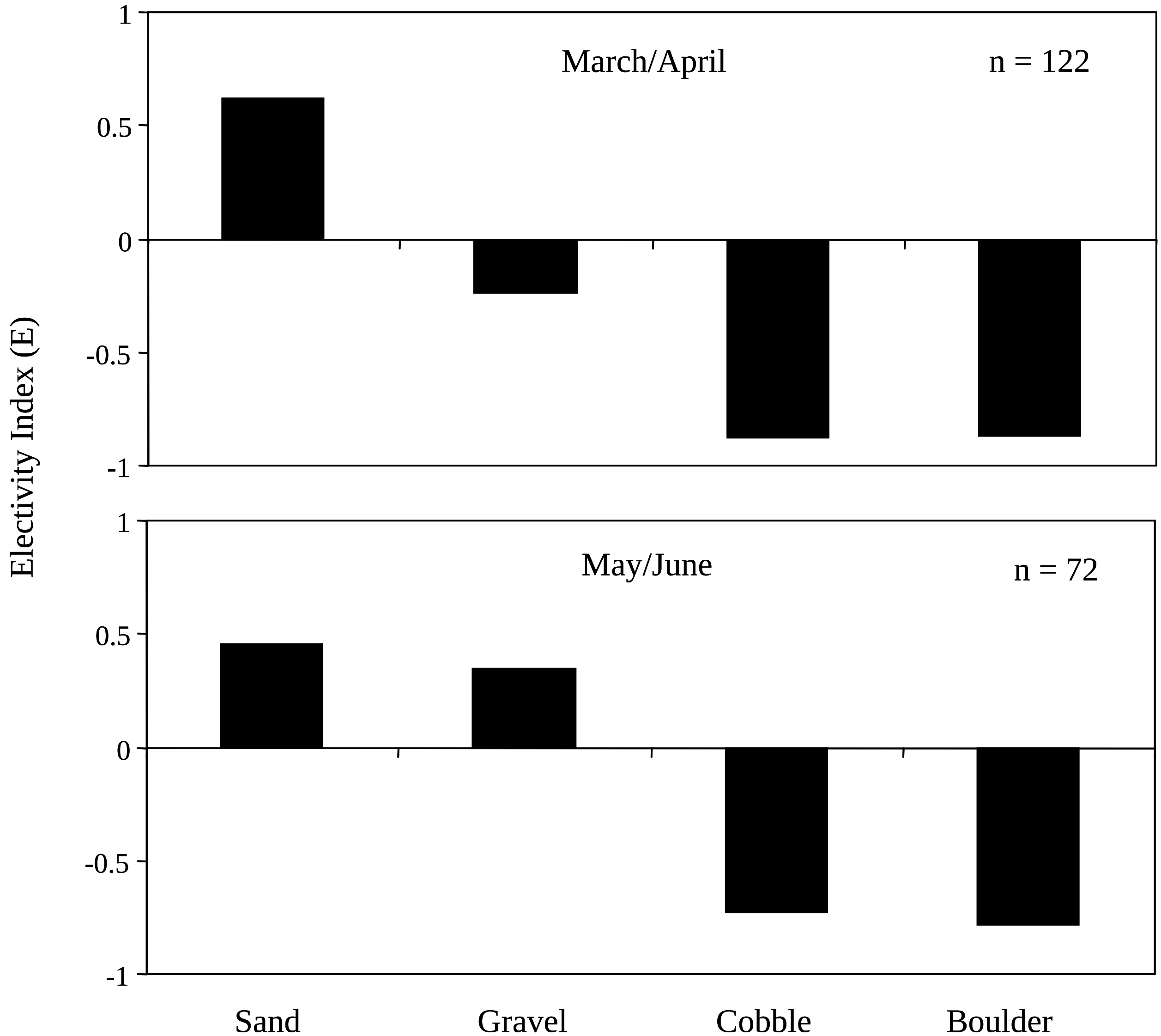


Figure 3. Mean density (fish/m^2) of juvenile chinook along the 0.4 and 0.7 m depth contours (+ 1 SE) in nearshore areas of southern Lake Washington during March-June, 2000. Number below each month indicates the number of surveys conducted during each month.

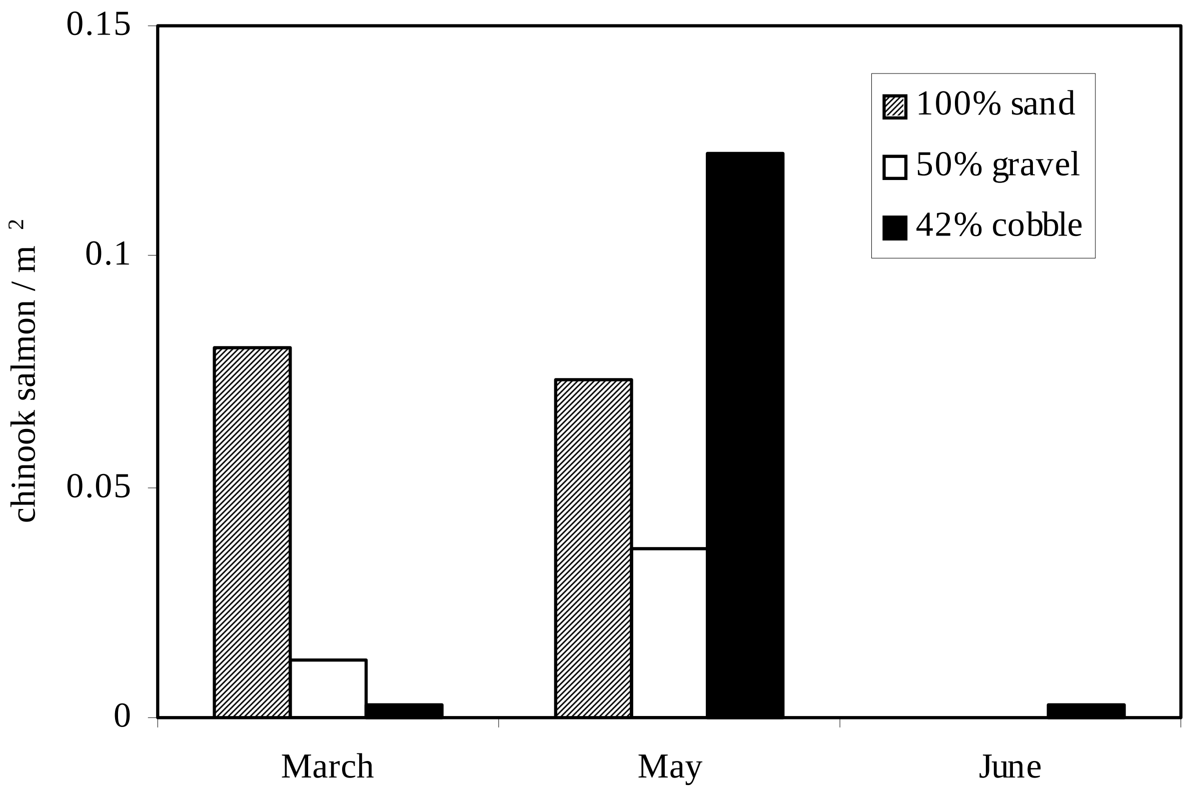
Figure 4. Electivity index values (E; Vanderploeg and Scavia 1979) for substrate use by juvenile chinook salmon in nearshore areas of southern Lake Washington during March/April and May/June, 2000 (sand: <5 mm; gravel: 5-49 mm; cobble: 50-249 mm; boulder: >249 mm). Positive index values indicate a preference and negative values an avoidance of each substrate



category. Numbers in the upper right corner of each graph show the number of chinook salmon measured for substrate use.

0.0 ND

Figure 5. Nocturnal densities of juvenile chinook salmon at three nearshore sites in southern Lake Washington during three survey dates occurring in March, May, or June, 2000. Each site had a different dominant substrate type of either sand, gravel, or cobble/gravel, with the percentage of dominate substrate at each site indicated. Fish densities were obtained by snorkeler



observations. ND indicates no data collected.

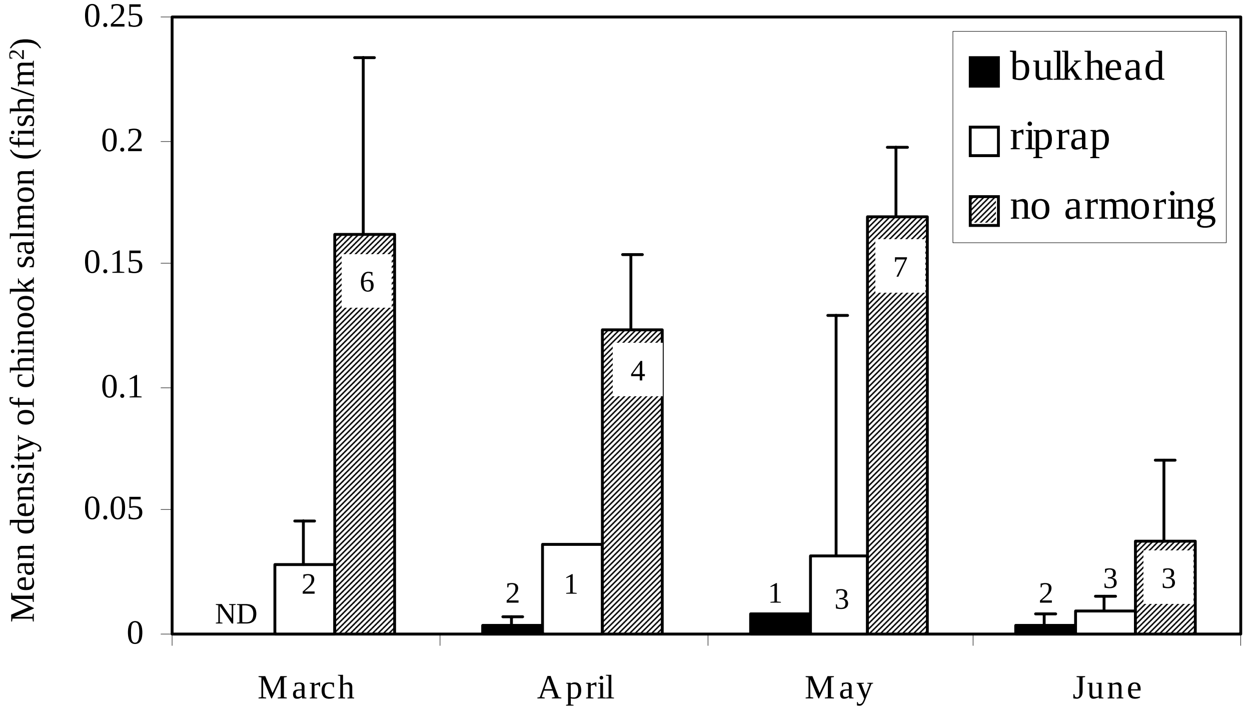


Figure 6. Mean density of juvenile chinook salmon (+1 SE) among nearshore sites with shorelines armored with bulkheading or rip-rap, or without armoring. Number of surveys completed shown within or above each bar. ND indicates no data.

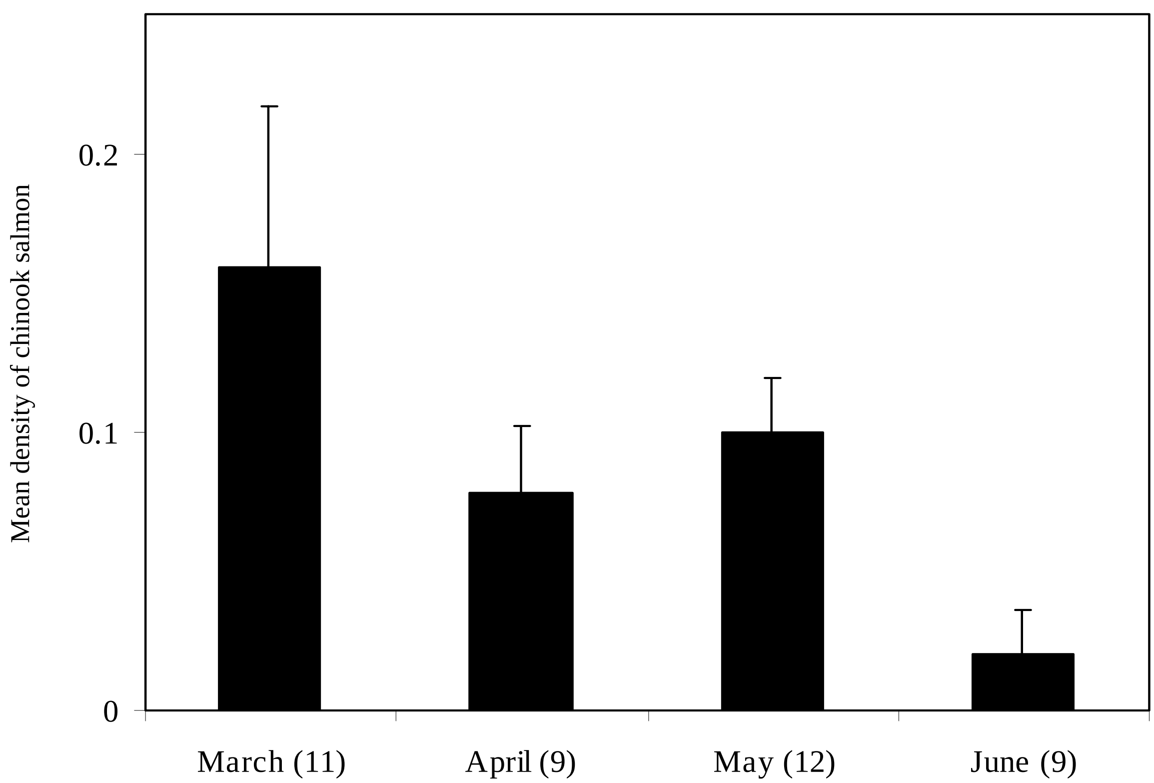


Figure 7. Mean density (fish/m^2) of juvenile chinook salmon (+ 1 SE) in nearshore areas of southern Lake Washington during March-June, 2000. Number in parentheses following each month indicates the number of surveys completed.

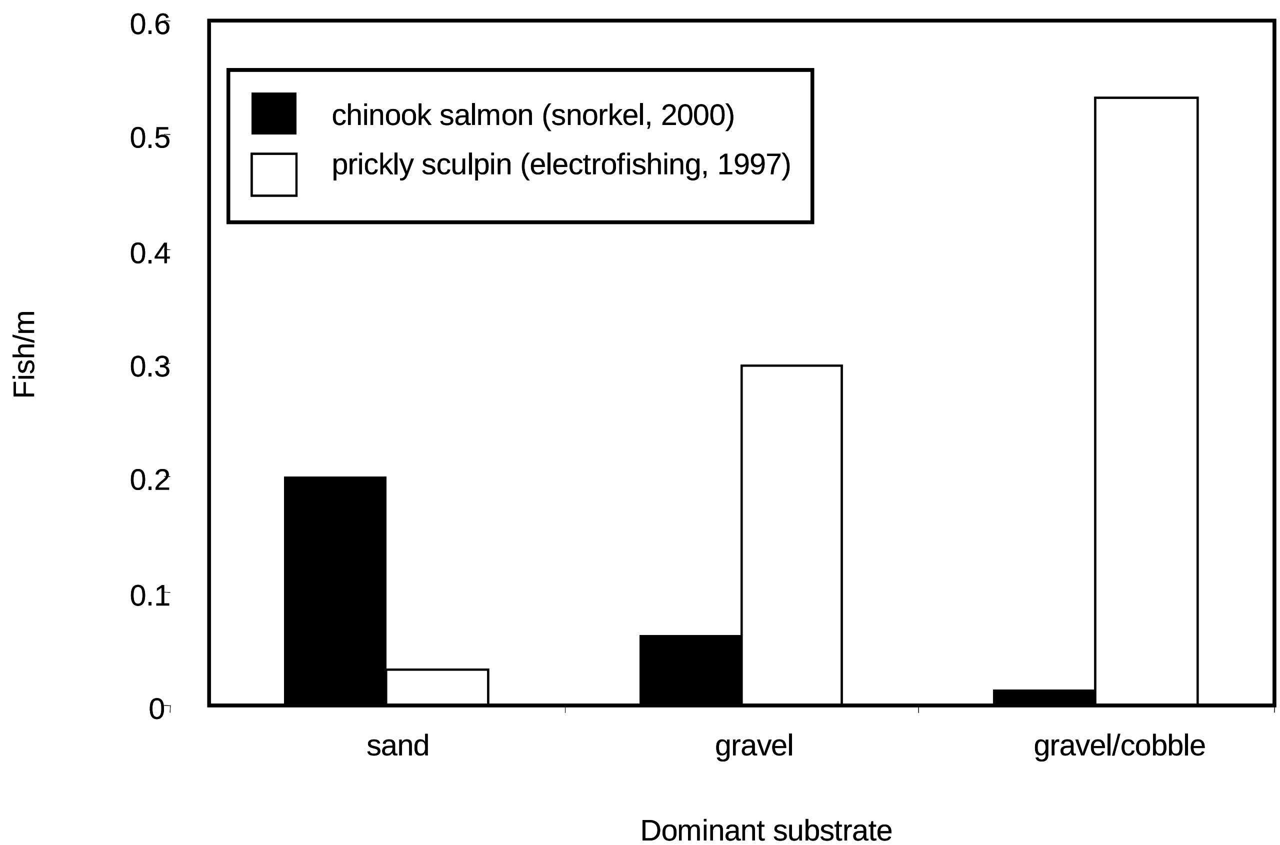


Figure 8. Density of juvenile chinook salmon and prickly sculpin over three substrate sizes (sand: <5 mm; gravel 5-25 mm; gravel/cobble: 25-250 mm) at three nearshore locations in southern Lake Washington. Data for chinook salmon were obtained by night snorkeling during this study, March and May, 2000. Data for prickly sculpin were obtained by night electrofishing, March and April, 1997. Data from both studies were collected at same three sites.

Appendix A. Number and density (fish/m^2)of fish by month along snorkeled transects in nearshore southern Lake Washington, March-June, 2000.

			Number of fish					Fish/m^2				
Fish type	Scientific name	Lifestage or size	March	April	May	June	Total	March	April	May	June	Total
Salmonidae												
chinook salmon	*Oncorhynchus tshawytscha*	juvenile	220	129	176	27	552	2.2	0.8	1.6	0.15	4.74
coho salmon	*O. kisutch*	juvenile			2		2			< 0.1		< 0.1
sockeye salmon	*O. nerka*	juvenile		15	49		64		0.2	0.4		0.5
cutthroat trout	*O. clarki*	adult/juvenile		23	4		27		0.1	< 0.1		0.2
unidentified trout		<200 mm		32	12	43	87		0.2	0.1	0.2	0.5
		>200 mm		3	1	8	12		0.1	< 0.1	0.1	0.1
Cyprinidae												
northern pikeminnow	*Ptychocheilus oregonensis*	adult				50	50				3.3	3.3
peamouth	*Mylocheilus caurinus*	juvenile	1	2	731	64	798	< 0.1	< 0.1	4.0	0.5	4.7
Cyprinidae spp		<75 mm		4			4		< 0.1			< 0.1
Catostomidae												
unidentified		larval/juvenile			30	504	534			0.2	13.9	14.1
Gasterosteidae												
threespine stickleback	*Gasterosteus aculeatus*	adult	8	618	970	63	1659	0.1	3.9	10.2	0.6	14.9
Centrarchidae												
smallmouth bass	*Micropterus dolomieui*	juvenile				4	4				< 0.1	< 0.1
		adult		7	2	2	11		< 0.1	< 0.1	< 0.1	0.1
pumpkinseed	*Lepomis gibbosus*	adult			2		2			< 0.1		< 0.1
unidentified				1		2	3		< 0.1		< 0.1	< 0.1

Appendix A. Continued.

Fish type	Scientific name	Lifestage or size	Number of fish March	April	May	June	Total	Fish/m² March	April	May	June	Total
Percidae												
yellow perch	*Perca flavescens*	juvenile				46	46				78.0	0.38
		adult	5	4	6	4	19	< 0.1	< 0.1	0.1	0.1	0.1
Cottidae												
prickly sculpin	*Cottus asper*	<75 mm	187	88	261	216	752	1.1	0.4	2.6	1.6	6.1
		>75 mm	79	110	232	156	577	0.6	0.6	2.1	1.3	4.5
Grand Total			500	1036	2478	1194	5209	4.3	6.3	21.4	22.4	54.4